MOSAIC AND SPINDLE TU[illegible] IN KANSAS POT TO FIELDS

by

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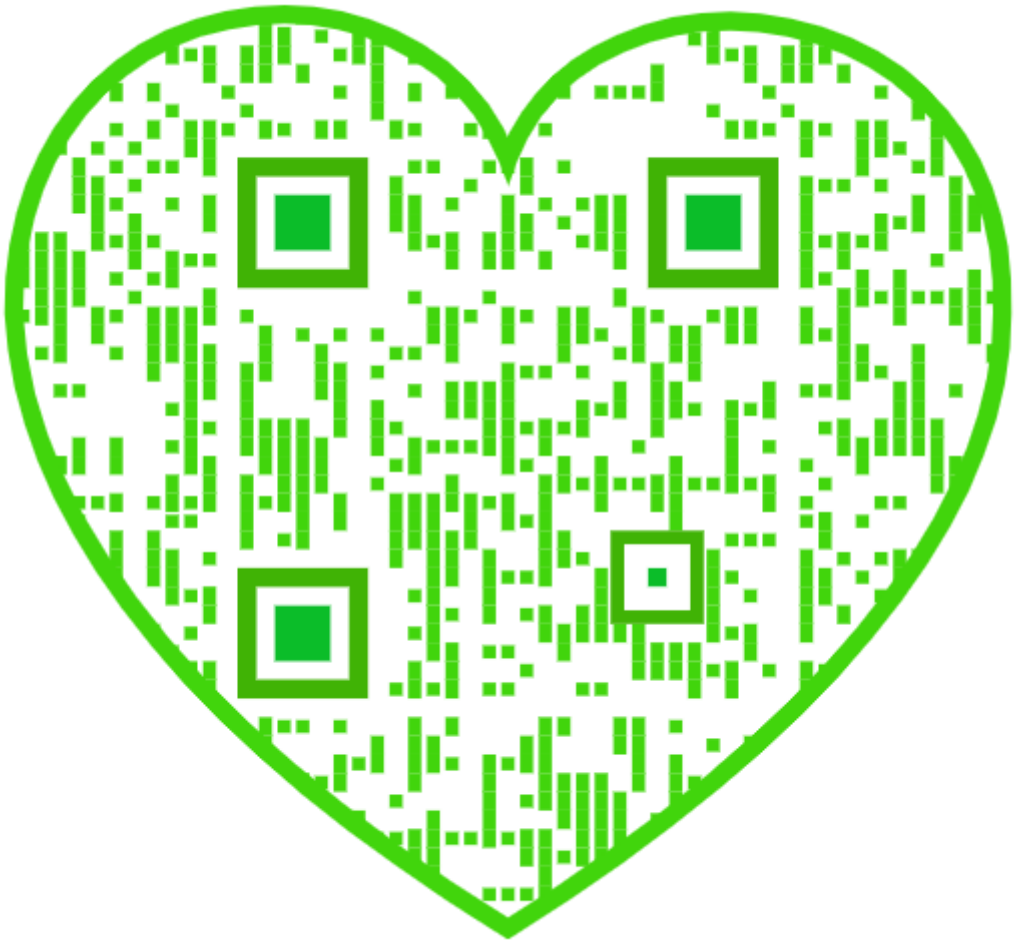

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TABLE OF CONTENTS

Page

INTRODUCTION - 3

REVIEW OF LITERATURE - - - - - - - - - - - - - - - - - - 5

MOSAIC STUDIES - 11

Materials and Methods - - - - - - - - - - - - - - - 11

Experimental Data - - - - - - - - - - - - - - - - - 16

Investigations, 1924 - - - - - - - - - - - - 17

Investigations, 1925 - - - - - - - - - - - - 19

Investigations, 1926 - - - - - - - - - - - - 23

Discussion - - - - - - - - - - - - - - - - - - - 24

SPINDLE TUBER STUDIES - - - - - - - - - - - - - - - - - 28

Materials and Methods - - - - - - - - - - - - - - 28

A. Transmission Studies - - - - - - - - - 29

B. Spindle Tuber Expression Studies - - - 35

C. Spindle Tuber Prevalence Studies - - - 35

Experimental Data - - - - - - - - - - - - - - - 36

Investigations, 1926 - - - - - - - - - - - 36

Investigations, 1927 - - - - - - - - - - - 43

Discussion - - - - - - - - - - - - - - - - - - - 47

SUMMARY - 51

BIBLIOGRAPHY - 53

MOSAIC AND SPINDLE TU[illegible] IN KANSAS POTATO FIELDS

by

Chester Eugene Graves

I[illegible]TRODUCTION

Virus diseases have been present in the potato growing districts of this country for many years. Potato seed growers have long realized that the control of virus diseases is one of their most difficult problems. These diseases cause a condition commonly known among the growers as "running out" of seed potatoes, hence they are classed generally as degeneration diseases.

Mosaic is perhaps the most wide spread and commonly recognized of the potato degeneration diseases. It is well known that a very high percentage of the potato fields in the North contain more or less mosaic infection. Kansas potato growers secure their seed potatoes each year from the North. It is very evident that much seed shipped into this state is grown from mosaic seed stock.

The most easily recognized foliage symptom of mosaic, as expressed in the northern states, is a mottled chlorosis in the leaves. The conspicuous absence of this leaf mottling in Kansas potato fields has caused considerable speculation as to how mosaic is expressed under our

conditions. It has even been suggested that the disease does not develop in Kansas hence does not affect the yield.

The purpose of these investigations, as far as potato mosaic is concerned, has been only to study the mode of potato mosaic expression in Kansas. The principal studies have been on plant characteristics, including size, shape, color and yield of mosaic infected plants as compared with healthy plants.

Spindle tuber is a serious degeneration disease of the potato that has not long been recognized. The cylindrical, pointed, or otherwise misshapen tubers that characterize the symptoms expressed by this disease have been observed for several years by growers and others working with potatoes. It has been noted that these tubers, known to commercial growers as "run out seed" or "lady fingers," decrease the yield when used for seed.

However, it was not realized until recently that the causal factor for this condition is a filterable virus, and furthermore, that the introduction of this virus into healthy plant tissue will produce the degeneration disease that we now call spindle tuber.

With the startling discovery that spindle tuber is transmissible came the realization that there are many possibilities, in the natural production and management

of a potato crop, for the dissemination of this disease. Contact of diseased and healthy cut seed pieces, insects feeding on diseased and healthy plants, contaminated tools such as cutting knives, pickers on the planter or other tools used for handling the potato crop may all furnish possible means for disseminating the causal agency of spindle tuber.

*The purpose of the investigations concerning spindle tuber has been (1) to study methods of dissemination, (2) to study the mode of expression in Kansas and (3) to determine the prevalence of visible spindle tubers in the seed potatoes that are shipped into Kansas from other states.

The experimental data contained in this thesis are based upon three years investigations on mosaic expression (1924-1925-1926) and two years investigations on spindle tuber dissemination, expression and prevalence (1926-1927).

REVIEW OF LITERATURE

The widespread interest in the virus diseases of plants began with the discovery by Mayer (1886) that tobacco mosaic is an infectious disease. Iowanowski (1892) found that the filtered fluid from mosaic infected

*The author is indebted to Dr. R. P. White for his valuable assistance and advice contributed during the progress of this work.

plants still possesses its infectious qualities. This opened the door to a new field in plant pathology; namely the field of filterable virus diseases of plants.

Beijerinck (1898) ascribed the cause of tobacco mosaic to a contagious, water soluble, non-corpuscular material which he called "contaguim vivum fluidum." Woods (1902) contended that mosaic is due to an oxidizing enzyme which causes the destruction of chlorophyll.

The immense amount of work done on mosaic transmission leaves no doubt as to the infectious nature of the virus when transferred from diseased to healthy tissue in plants of the same species. Furthermore, a great deal of evidence has been obtained which proves conclusively that cross-inoculations of mosaic are successful when the virus from infected plants of certain genera, families or orders is introduced to certain plants of other genera, families or orders.

Elmer (1925) working with healthy tomato plants secured cross-infections with the virus from sugar cane, bean, crookneck squash, zinnia, calendula, velvet leaf, milkweed, catnip and martynia. He also secured infection of the cow pea from egg plant, potato, cucumber and crookneck squash. Petunia plants became infected with the mosaic virus from cucumber and crookneck squash while

the virus from infected celery and spurge plants was transmitted to cucumbers.

Schultz and Folsom (1923) verified the work of others on insect transmission of degeneration diseases of the potato in the field. Some of their findings on transmission, variations of symptoms and control measures are summarized as follows: "In Green Mountains, mild mosaic was not transmitted by contact except in stem and tuber grafts. In Green Mountains, aphids from a 'curly dwarf' combination, apparently consisting of leaf-rolling mosaic and spindling-tuber together, transmitted the curly-dwarf combination to a part of the hill and spindling tuber alone to the other part, distinction being made between different tuber units of the second generation. Natural transmission by insects contributes to the difficulty of the control problem. Mosaic symptoms from the same seed tubers show different complexes in different environments. Mottling is suppressed by southern regions and by higher temperatures. Dwarfing of the tubers, and therefore reduction in yield rate, was more pronounced in a southern region. Shading tended to increase mosaic mottling and to decrease leaf rolling. Selection of tubers without knowledge of the parent plants cannot eliminate seed from diseased plants infected late

the preceding season. Proximity and heavy aphid infestation increased the spread of mild mosaic while sufficient isolation from diseased stocks reduced it so that a state of freedom from the disease was maintained. Isolation by 30 meters was insufficient, and over 400 meters was sufficient."

Johnson (1927) working with classification of viruses reports eleven different mosaic viruses on tobacco and related plants. More than one virus may exist in a single plant. He found it possible to separate these on the basis of characteristic symptoms in infected plants.

Schultz and Folsom (1925) recognised four types of potato mosaic and classified them according to foliage symptoms. These four types are: (1) Mild mosaic, which is characterized by clear cut mottling, some wrinkling, ruffling and slight dwarfing of the foliage. (2) Leaf-rolling mosaic which shows diffused mottling and slight rolling upward of the leaves. Leafroll is distinguished from leafrolling mosaic by absence of dwarfing, rigidity and chlorosis. (3) Rugose mosaic is characterized by somewhat diffused mottling, rugosity and distinct dwarfing. Tuber reduction is more marked than in mild mosaic. (4) Crinkle mosaic resembles mild mosaic in its clear cut

mottling but is characterized by considerable wrinkling and ruffling.

Martin (1922) was the first to apply the name "spindle tuber" to the long, cylindrical, misshapen tubers commonly known by growers as "run out seed." Schultz and Folsom (1923) definitely established the infectious nature of the causal agency.

Schultz and Folsom (1925) describe spindle tuber symptoms as: "spindling stems and upright and somewhat darker green and slightly rugose and dwarfed foliage. Abnormally spindling, spindle shaped and usually dwarfed tubers with more or less conspicuous and apparently numerous eyes are characteristics of this disease."

Goss (1925) describes spindle tuber foliage as: "usually dwarfed and erect, with fewer stalks per hill. The branches point upwards, and the leaves are small with wavy or ruffled margins. Affected tubers are longer and more cylindrical in shape than normal healthy tubers of the same variety, and are sometimes irregular and bumpy. The bud end of the tuber is more pointed and the tuber becomes spindle shaped. The eyes are more numerous, very shallow, and sometimes even bulge out. In the red varieties such as Bliss Triumph the color is much paler than normal and blotchy."

Werner (1926) in writing of the habit of the spindle tuber plant says: "Spindle tuber retards plant growth, when compared with normal plants, as manifested by a slower rate of plant emergence, low per cent of sprouting, and the development of small and less vigorous plants. Spindle tuber plants have an erect habit of growth. The leaves are smaller and narrower than normal. They are folded up along the midrib and are wavy along the margin. Spindle tuber has been found in all varieties tested (representing ten variety groups). No instance of immunity or resistance was discovered."

Werner (1926) doubted that aphids were responsible for transmitting the causal agency of spindle tuber in western Nebraska because there are few aphids in that part of the state. Goss (1928), in a paper presented at the nineteenth annual meeting of the American Phytopathological Society, reports that the transmission of this virus can be brought about by grasshoppers. Twenty-nine cases of infection were secured out of sixty-four inoculations. The plants inoculated were grown under cages. The uncaged controls remained healthy.

Goss (1926) reports successful inoculations of spindle tuber virus with a cutting knife contaminated with juice from a spindle tuber which was used to cut healthy tubers. Healthy seed pieces were successfully inoculated

by contact with the cut surface of a spindle tuber.

In testing artificial means of transmission of spindle tuber, Folsom (1923), used tuber grafts. He was successful in securing infections in 83 per cent of the trials. Leaf mutilations and stem grafts also gave infection to the degree that current season symptoms of spindle tuber were expressed by the progeny of the plants inoculated.

Goss and Peltier (1925) found from their experiments that spindle tuber reacts to temperature conditions in the exact reverse to mosaic. It was often impossible to distinguish plants affected with spindle tuber when they were grown at low temperatures and the symptoms were increasingly evident as the temperatures were raised.

Werner (1926) reports greater elongation of spindle tubers at high temperatures in heavy soils of high moisture content. Furthermore, infected plants grown under favorable conditions produced better type tubers than healthy plants grown under unfavorable conditions.

MOSAIC STUDIES

Materials and Methods

The investigations herein reported concerning mode of expression of mosaic in Kansas include data obtained

by tuber indexing and studying the progeny of 1,002 individual tubers which produced approximately 4000 plants.

The tubers used for these studies were secured from Wisconsin, Minnesota, North Dakota, Washington, Idaho, Maine and Missouri. Most of the lots of seed received were of known parentage. Some had been grown in insect proof cages to insure against accidental infection. Others were obtained from fields known to contain heavy infection of mosaic. A few lots of seed were taken from commercial stocks on the market.

The following tables describe the various lots of seed used, their origin, the variety, the infection carried and the index numbers given to the tubers in each lot of seed for the year the seed was planted.

Table I. Seed for Mosaic Studies - 1924

Tuber Index No.	Infection Carried	Variety	Origin
1 - 76	Mosaic	Triumphs	Wisconsin
81 - 141	Mosaic and Leafroll	Burbanks	Washington
142 - 163	Curly dwarf	Triumphs	Idaho
164 - 214			
M1 - M20			
R31 - R40	Mosaic		
M46 - M50	Leafroll	Green	
L61 - L70	Spindle tuber	Mountain	Maine
215 - 314	Unknown	Early Ohio	Market
315 - 414	Unknown	Irish Cobbler	Market

Table II. Seed for Mosaic Studies - 1925

Index No.	Infection Carried	Variety	Origin
1 - 15	Mosaic	Triumphs	Minnesota
16 - 27	Mosaic	Triumphs	Wisconsin
28 - 42	Mosaic	Triumphs	Minnesota
43 - 50	Mosaic and Spindle Tuber	Green Mountains	North Dakota
51 - 58	Mosaic and Spindle Tuber	Early Ohio	North Dakota
59 - 66	Mosaic and Spindle Tuber	Irish Cobbler	North Dakota
67 - 93	Mosaic	Early Ohio	Missouri
94 - 119	Mosaic	Irish Cobbler	Missouri
120 - 309	Unknown	Early Ohio	Market
310 - 455	Unknown	Irish Cobbler	Market

Table III. Seed for Mosaic Studies - 1926

Index No.	Infection Carried	Variety	Origin
1 - 80	Healthy	Irish Cobbler	Minnesota
81 - 90	Mosaic	Irish Cobbler	Minnesota

Sixteen lots of seed from different sources were used in 1924 and 1925. These lots of seed carried mosaic, leafroll and spindle tuber. A careful study of the progeny of each tuber was made in the greenhouse and in the field in order to become acquainted with the mode of expression of these diseases.

In 1926 only the Irish Cobbler variety was used because this variety is the principal one grown in the commercial districts in the state. This seed was selected in Minnesota from a field that contained a high infection of Mosaic. Forty tubers from mosaic infected hills and fifty tubers from apparently healthy hills were furnished by A. G. Tolaas, in charge of Potato Seed Certification work in Minnesota.

Tuber Indexing: In order to secure data on the progeny of each individual tuber an indexing system was used. This work consisted in numbering each individual tuber. The index number of each tuber was inscribed on the tuber with India ink. The plants produced by each tuber unit were staked, both in the greenhouse and in the field, each stake carrying the index number of each tuber unit.

Greenhouse Studies: Previous investigations by several workers show that mosaic foliage symptoms show most distinctly on plants that are grown at cool temperatures and in diffused sunlight. Therefore, it was thought advisable to produce one plant from each tuber in the greenhouse where these conditions could be obtained.

For the greenhouse study, one eye was cut from each tuber and planted in a 5 inch pot. The pot was given the

index number on the tuber from which this eye was taken. The remainder of the tuber was stored for field plantings. As soon as the plants in the greenhouse were large enough to express foliage symptoms notes were taken and recorded. No yield data were taken in the greenhouse because the pots were too small to secure normal yields. The object of the greenhouse study was to determine which tubers carried the mosaic virus and which ones were healthy. This was necessary because under the intense sunlight of field conditions the foliage symptoms are often masked.

Field Studies: The portion of the tuber saved from tuber indexing study in the greenhouse was used for making a field study of mosaic. Each tuber still carried the index number given it before the greenhouse plantings were made. These tubers were cut into from two to four seed pieces which constituted a "tuber unit." Each tuber unit was planted in a short row of from two to four hills and was staked, the stake carrying the index number of the tuber from which the tuber unit was taken.

When the plants in the field were about ten inches high the first field notes were taken. The foliage of each tuber unit was inspected carefully to determine the symptoms expressed. A record was made indicating the symptoms expressed by each tuber unit. Field notes were taken a second time when the plants were in bloom. The

third set of field notes was taken when the tubers were harvested. Each tuber unit was harvested and the progeny weighed separately in order to compare yields of diseased and healthy tuber units.

In order to shorten the work of taking notes and to make it possible to formulate tables describing mosaic foliage symptoms a system of abbreviations was used. The letter used describes the symptoms expressed on the foliage of plants grown in the greenhouse or under field conditions.

Key to Abbreviations Describing Foliage

H - Healthy Appearance

M - Mild mosaic - Mottling only

RM - Rugose mosaic - Rugosity and mottling

LM - Leafrolling mosaic - Leafrolling and mottling

L - Leafroll only

EXPERIMENTAL DATA

Utilizing the methods just described, studies were made of the mode of expression of mosaic by plants and by the progeny of the various lots of seed obtained. The results of these studies follow. In presenting the data each lot of seed is treated separately for the year in which the work was done.

The following tables show the number of tubers

expressing each type of mosaic or other symptoms when planted in the greenhouse, and the subsequent expression of symptoms by progeny of these same tubers when grown under Kansas field conditions.

Investigations, 1924

Table IV. Bliss Triumphs from Wisconsin Produced in a Field Heavily Infected with Mosaic. Index No. 1 - 76.

Greenhouse Symptoms March 27	Field Symptoms June 1					Field Symptoms June 15					Average hill yield ounces
	H		RM	LM	L	H		RM	LM	L	
6 Tubers Mild Mosaic	5			1		5			1		16¼
67 Tubers Rugose Mosaic	3	22	2	39	1	2	3	3	22		11½

Table V. Russet Burbank Tubers from a Field in Washington Containing a High Infection of Mosaic and Leaf-roll. Index No. 81 - 141.

Greenhouse Symptoms March 27	Field Symptoms June 1						Field Symptoms June 15						Average hill yield ounces
	H			L						LM	L		
15 Tubers Healthy	8	1		3	3	6			5	4			None
11 Tubers Mild Mosaic	2	2		4	3	1			6	4			"
11 Tubers Rugose Mosaic				11					11				"
4 Tubers Leafroll Mosaic				4					4				"
7 Tubers Leafroll only	3			1	3				1	6			"

Table VI. [illegible] from Idaho fro[illegible] Field Heavily Infected with Curly Dwarf. Index No. 142 - 163.

Greenhouse Symptoms March 27	Field Symptoms June 1 H	M	L	Field Symptoms June 15 H	M	L	Average hill yield ounces
9 Tubers Healthy	2		7			7	2	None
4 Tubers Mild Mosaic	1		3			3	1	"
3 Tubers Leafroll Only	2	1				1	2	"
6 Tubers Rugose Mosaic	2	1	2	1		5	1	"

Table VII. Green Mountains from Maine Carrying Infection of Mild Mosaic, Rugose Mosaic, Leafrolling Mosaic, Leafroll and Spindle Tuber. Index No. 164 - 214. H1 - H20; M1 - M40; M46 - [illegible]; L1 - L40.

Greenhouse Symptoms March 27	Field Symptoms June 1 H	M	L	Field Symptoms June 15 H	M	L	Average hill yield ounces
22 Tubers Healthy	26	4	9	2	23	1	8	9	13½
13 Tubers Mild Mosaic		7	4	2	1	6	4	2	10
13 Tubers Rugose Mosaic	1	18				17	2		6½
4 Tubers Leafroll Mosaic			4				4		1½
13 Tubers Leafroll Only			4	9			3	10	2

Table VIII. Early Rios from Market Stock. Infection Unknown. Index No. 215 - 314.

Greenhouse Symptoms March 27	Field Symptoms June 1			Field Symptoms June 15			Average hill yield ounces
	H	M		H	M		
7 Tubers Healthy	7			7			19½
5 Tubers Mild Mosaic	1	4		3	2		15½
1 Tuber Rugose		1		1			9

* 100 tubers were indexed in the greenhouse. Only six tubers showed mosaic symptoms. These, together with seven healthy tubers were used for field planting.

Table IX. *Irish Cobbler Seed from Market Stock. Infection Unknown. Index No. 315 - 414.

Greenhouse Symptoms March 27	Field Symptoms June 1			Field Symptoms June 15			Average hill yield ounces
	H	M		H	M		
7 Tubers Healthy	7			7			25
1 Tuber Mild Mosaic		1		1			22½

* 100 tubers were indexed in the greenhouse. Only one plant showed a very light form of mild mosaic. This tuber and seven healthy tubers were used for field planting.

Investigations, 1925

Table X. Bliss Triumphs from Jones Bros., Pitt, Minnesota, from a Field Containing a High Infection of Mosaic. Index No. 1 - 15.

Greenhouse Symptoms March 29	Field Symptoms May 15			Field Symptoms June 3			Average hill yield ounces
	H	M	MM	H	M	MM	
2 Tubers Healthy	2			2			6¾

Greenhouse Symptoms March 29	Field Symptoms May 15			Field Symptoms June 3			Average hill yield ounces
	H	M	RM	H	M	RM	
10 Tubers Mild Mosaic	1	9		7	3		3
3 Plants Rugose Mosaic	1		2	1		2	3½

Table XI. Bliss Triumphs from J. W. Brann, Madison, Wisconsin. Parent Field Showed High Mosaic Infection. Index No. 26 - 27.

Greenhouse Symptoms March 29	Field Symptoms May 15			Field Symptoms June 3			Average hill yield ounces
	H	M	RM	H	M	RM	
3 Tubers Spindle Tuber	2	1		2	1		5 2/3
3 Tubers Mild Mosaic	1	2		1	2		4½
6 Tubers Rugose Mosaic	1	4	1	2	4		8 1/3

Table XII. Bliss Triumphs from Sid Mason, Williams, Minnesota, from a Field Showing Only Light Mosaic Infection. Index No. 28 - 42.

Greenhouse Symptoms March 29	Field Symptoms May 15			Field Symptoms June 3			Average hill yield ounces
	H	M	RM	H	M	RM	
11 Tubers Healthy	11			11			7½
4 Tubers Mild Mosaic	1	3		3	1		4½

Table XIII. Green Mountains from H. L. Bolley, Fargo, North Dakota, from a Field Containing High Infection of Mosaic and Spindle Tuber. Index No. 45-50.

Greenhouse Symptoms March 29	Field Symptoms May 15 H	M	RM	Field Symptoms June 3 H	M	RM	Average hill yield ounces
2 Tubers Healthy	2			2			None
4 Tubers Mild Mosaic	3	1		3	1		"
2 Tubers Rugose Mosaic		2			2		"

Table XIV. Early Ohios from H. L. Bolley, Fargo, North Dakota, from a Field Containing a High Per Cent of Mosaic and Spindle Tuber. Index No. 51 - 58.

Greenhouse Symptoms March 29	Field Symptoms May 15 H	M	RM	Field Symptoms June 3 H	M	RM	Average hill yield ounces
3 Tubers Healthy	3			3			14
4 Tubers Mild Mosaic	1	3		1	3		7
1 Tuber Rugose Mosaic			1			1	4

Table XV. Irish Cobblers from H. L. Bolley, Fargo, North Dakota, from a Field Containing a High Per Cent of Mosaic and Spindle Tuber. Index No. 59 - 66.

Greenhouse Symptoms March 29	Field Symptoms May 15 H	M	RM	Field Symptoms June 3 H	M	RM	Average hill yield ounces
6 Tubers Healthy	6			6			14
2 Tubers Mild Mosaic	2			2			0

Table XVI. Early Ohios from J. T. Quinn, Columbia, Missouri, from a Field that Showed 3 Per Cent Mosaic. Index No. 67 - 93.

Greenhouse Symptoms March 29	Field Symptoms May 15 H	M	RM	Field Symptoms June 3 H	M	RM	Average hill yield ounces
22 Tubers Healthy	17	4	1	17	4	1	6
4 Tubers Mild Mosaic		4		1	3		4
1 Tuber Rugose Mosaic		1			1		3

Table XVII. Irish Cobblers from J. T. Quinn, Columbia, Missouri, from a Field Showing a Very Small Per Cent of Mosaic Infection. Index No. 94 - 119.

Greenhouse Symptoms March 29	Field Symptoms May 15 H	M	RM	Field Symptoms June 3 H	M	RM	Average hill yield ounces
25 Tubers Healthy	23	2		25			7
1 Tuber Mild Mosaic		1		1			3

Table XVIII. Early Ohios from Market Stock. Infection Unknown. Index No. 120 - 309.

Greenhouse Symptoms March 29	Field Symptoms May 15 H	M	RM	Field Symptoms June 3 H	M	RM	Average hill yield ounces
10 Tubers Healthy	9	1		10			None
11 Tubers Mild Mosaic	2	9		5	6		"
12 Tubers Rugose Mosaic	1	6	5	1	10	1	"

Table XIX. Irish Cobblers from Commercial Stocks. Infection Unknown. Index No. 310 - 453.

Greenhouse Symptoms March 29	Field Symptoms May 15 H	M	RM	Field Symptoms June 3 H	M	RM	Average hill yield ounces
10 Tubers Healthy	8	2		10			4½
4 Tubers Mild Mosaic		4		2	2		4½
12 Plants Rugose Mosaic	7	2	3	9		3	4

Investigations, 1926

Table XX. Irish Cobblers Selected by A. O. Tolaas, St. Paul, Minnesota, from Disease-free Hills in a Field that Contained a High Per Cent of Mosaic. Index No. 1 - 50.

Greenhouse Symptoms April 5	Field Symptoms May 22 H	M	RM	Field Symptoms June 4 H	M	RM	Average hill yield ounces
38 Tubers Healthy	38			38			11½
5 Tubers Mild Mosaic	5			5			8
7 Tubers Rugose Mosaic		5	2		7		4½

Table XXI. Irish Cobblers Selected by A. O. Tolaas, from Mosaic Infected Hills. Index No. 51 - 90.

Greenhouse Symptoms April 5	Field Symptoms May 22 H	M	RM	Field Symptoms June 4 H	M	RM	Average hill yield ounces
26 Tubers Mild Mosaic	21	5		23	3		6
14 Tubers Rugose Mosaic		8	6		8	6	5½

DISCUSSION

The foliage symptoms expressed by the three different types of mosaic studied when grown under conditions favorable for the disease, as were present in the greenhouse, are as follows:

1. Mild Mosaic -- Mottling of the leaves into fairly well defined light and dark green patches. Often the leaves are slightly wrinkled and more or less dwarfed.

2. Rugose Mosaic -- Pronounced depressions of even depth in the leaf surface at the veins with the prominences between the veins of very uniform height; accompanied by diffused mottling.

3. Leafrolling mosaic -- Expressed by a rolling upward of the leaves; may be distinguished from wrinkling due to the prominences in rugose mosaic being of equal height and the depressions of equal depth, while with ordinary wrinkling the depressions and prominences are unequal in depth and height.

Expression of the foliage symptoms of these types of mosaic in the field may be the same as are expressed in the greenhouse especially if cool and cloudy weather persists. However, as soon as a period of intense sunlight and high temperature prevails the symptoms usually change.

These symptoms apparently vary with the type of

mosaic carried by the plant and with the variety. The usual changes in symptoms in Irish Cobblers, as the growing season progresses are: (1) masking of the mottling in the case of mild mosaic and (2) loss of rugosity in the case of rugose mosaic leaving only the mottling. In some cases both rugosity and mottling are masked and the plant is apparently healthy.

In the case of the Early Ohio, mottling is not masked as frequently as with the Irish Cobbler. There is, however, a strong tendency toward masking as the season progresses. The changes in rugose mosaic symptoms in the Early Ohio is toward loss of rugosity and in some cases mottling is masked.

The behavior of the Bliss Triumph variety as regards masking of symptoms of mild mosaic is practically the same as in the Early Ohio. Tuber units that expressed typical rugose mosaic symptoms in the greenhouse often exhibited the symptoms of leafrolling mosaic in the field. Probably both leafrolling mosaic and rugose mosaic were present in certain tuber units but only rugose symptoms were recognized in the greenhouse because leafrolling symptoms are suppressed by shading. Throughout the season the Green Mountain variety expressed mosaic symptoms the most consistently of the varieties studied. In each case the symptoms expressed in the greenhouse were also

exhibited in the field by a large proportion of the tuber units. This was especially true in the case of ragose mosaic and leafrolling mosaic.

The following tables summarize the data obtained on each variety that was grown in the experiment for the entire three years. These tables show the number of tuber units that produced healthy plants or expressed the different types of mosaic in the greenhouse. The tables also show the number of sister plants from the same tuber unit that expressed symptoms of each type of mosaic during the subsequent growing season in the field.

Table XXII. Irish Cobbler Variety Comparing Foliage Symptoms Expressed in the Greenhouse and in the Field.

Greenhouse Symptoms	Field Symptoms Plants 10" high			Field Symptoms Plants in bloom		
	N	M	RM	N	M	RM
86 Tubers Healthy	82	4		86		
39 Tubers Mild Mosaic	26	13		34	5	
33 Tubers Ragose Mosaic	7	15	11	9	18	6

Table XXIII. Early Ohio Variety Comparing Foliage Symptoms Expressed in the Greenhouse and in the Field.

Greenhouse Symptoms	Field Symptoms Plants 10" high			Field Symptoms Plants in bloom		
	H	M	MI	H	M	[illegible]
32 Tubers Healthy	27	4	1	27	4	1
13 Tubers Mild Mosaic	2	11		5	8	
3 Tubers Rugose Mosaic		2	1	1	1	1

Table XXIV. Bliss Triumph Variety. Comparing Foliage Symptoms Expressed in the Greenhouse and in the Field.

Greenhouse Symptoms	Field Symptoms Plants 10" high					Field Symptoms Plants in bloom				
	H	M	MI	LM	L	H	M	[illegible]	LM	L
22 Tubers Healthy	15			7		13			7	2
27 Tubers Mild Mosaic	8	14		4	1	16	6		4	1
82 Tubers Rugose Mosaic	7	27	7	39	2	5	39	5	27	6

Table XXV. Green Mountain Variety. Comparing Foliage Symptoms Expressed in the Greenhouse and in the Field.

Greenhouse Symptoms	Field Symptoms Plants 10" high					Field Symptoms Plants in bloom				
	H	M	[illegible]	LM	L	H	M	[illegible]	LM	L
44 Tubers Healthy	28	4	1	9	2	25	1	1	8	9
17 Tubers Mild Mosaic	3	8	4	2		4	7	4	2	
21 Tubers Rugose Mosaic		3	18				2	17	2	
4 Tubers Leafroll Mosaic				4					4	
13 Tubers Leaf roll Only				4	9				3	10

The tuber symptoms expressed were a decrease in size and number, hence a decrease in yield per hill. A review of Tables IV to XXI shows that the average yield per hill of healthy tubers was greater than that from tubers carrying mild mosaic, rugose mosaic, leafrolling mosaic or leafroll.

Mild mosaic reduced the yield per hill from ten to fifty per cent. Rugose mosaic usually decreased the yield from fifty to seventy-five per cent. This was true where foliage symptoms were masked as well as where foliage symptoms were not masked. Leafrolling mosaic often caused early death and very few tubers were produced on hills that survived.

SPINDLE TUBER STUDIES

Materials and Methods

The investigations herein reported concerning the transmission, expression and prevalence of spindle tuber include data obtained from two years study (1926-1927) of the dissemination, symptoms expressed and percentages of visible spindle tuber contained in various lots of commercial seed shipped into Kansas from northern states.

The tubers used for these studies were obtained from the following sources:

1. Spindle tubers from the Department of Botany and Plant Pathology, University of Nebraska, for transmission and expression studies.
2. Kansas spindle tubers selected from the general crop raised by Chas. Speaker, Kansas City, Kansas, R. R. #2.
3. Minnesota commercial seed. Selected for typical Cobbler type and apparently free from spindle tuber. These were used in the transmission studies.
4. Spindle tubers and good type tubers from commercial seed. This seed was used in studies on the expression of symptoms of spindle tuber.
5. Sack lots of commercial seed from various sources were used for determining percentage of visible spindle tuber being shipped into the state.

A. Transmission Studies

1. Insect Dissemination: The object of these studies was to determine whether or not spindle tuber is transmitted in the field by insects feeding on diseased and healthy plants.

Methods of Inoculation: A good type apparently healthy Irish Cobbler tuber was cut into four seed pieces with a sterile knife and planted in a short row. Closely surrounding these plants were planted a number of seed

pieces cut from spindle tubers.

As a check, another good type apparently healthy Irish Cobbler tuber was cut into four pieces with a sterile knife and planted nearby. Seed pieces from spindle tubers were planted surrounding these four seed pieces. An insect proof cage of cheese cloth was built over this check.

2. Artificial Inoculation: The object of these experiments was to determine whether or not the spindle tuber causal agency is transmissible by artificial methods that simulate injuries produced by sucking and chewing insects.

(a) Contaminated Needle Punctures in Leaves and Petioles Simulating Insect Punctures.

Methods of Inoculation: Seed pieces from apparently healthy good type tubers were planted. When the plants were about a foot high inoculations were made by inserting a sterile needle into a typical spindle tuber infected plant and then puncturing the leaves and petioles of a healthy plant with the contaminated needle.

(b) Maceration of Leaves with Contaminated Fingers, Simulating Damage Done by Colorado Potato Beetle in the Field.

Methods of Inoculation: Seed pieces from good type apparently healthy tubers were planted. When the plants

were about a foot high inoculations were made by crushing the leaves of a spindle tuber infected plant between the thumb and forefinger and then immediately rubbing the contaminated fingers on the leaves of healthy plants, exerting just enough pressure to break the leaf epidermis. Thirty plants were treated in this manner.

3. Cutting Knife Dissemination: The object of these experiments was to determine whether or not the causal agency of spindle tuber may be transmitted by contaminated cutting knives.

Method of Inoculation: A good type tuber was halved lengthwise through the bud end with a sterile knife. One half was then cut into two seed pieces with a knife that had just been used to cut a spindle tuber. The sister half was cut into two seed pieces with a sterile knife to serve as a check on the inoculated half.

The two seed pieces from the inoculated half were planted fourteen inches apart in one row. The two seed pieces from the uninoculated sister half were planted just opposite in the adjoining row.

In 1926 this experiment was repeated twelve times at the Chas. Speaker farm at Kansas City and ten times in the experimental field at Manhattan making a total of forty-four hills of inoculated material and forty-four

uninoculated sister hills.

In 1927 this was repeated twelve times in the experimental field at Manhattan making twenty-four hills of inoculated seed pieces and twenty-four uninoculated sister hills.

4. Dissemination by Contact of Cut Surfaces: The object of these experiments was to determine whether or not the cut surface of a spindle tuber seed piece coming in contact with the cut surface of a healthy seed piece would transmit the disease to the healthy seed piece.

Method of Inoculation: A good type tuber was halved lengthwise through the bud end with a sterile knife. A spindle tuber was then halved and the freshly cut surface rubbed against the freshly cut surface of one-half of the good type tuber. The inoculated half and the uninoculated sister half were each cut into two seed pieces with a sterile knife. The two seed pieces from the inoculated half were then planted in one row and the two uninoculated sister quarters were planted just opposite in an adjoining row.

In 1926 this experiment was repeated twelve times at the Chas. Speaker farm near Kansas City and ten times in the experimental farm at Manhattan, making a total of forty-four inoculated hills and forty-four uninoculated sister hills.

In 1927 this was repeated twelve times in the experimental field at Manhattan, making twenty-four inoculated hills and twenty-four uninoculated sister hills.

5. Transmission by tuber grafts: Since contact of freshly cut surfaces gives only a short time for infection to take place before the surfaces dry, a test was planned whereby contact of cut surfaces might be secured for a considerable length of time. Tuber grafting was the means whereby this was accomplished.

Method of Inoculation: A sterile cork borer was used to cut a hole through a good type tuber. By means of the cork borer a round plug was then cut out of a spindle tuber and fitted tightly into the hole in the good type tuber. The whole tuber was then planted.

This experiment was repeated ten times at the Spaker farm at Kansas City and thirty-six times in the experimental field at Manhattan, making a total of forty-six trials.

6. Planter Box Dissemination: The juice from cut seed pieces often causes the planter box to become wet. In order to test the transmissibility of spindle tuber virus from the wet sides of the planter hopper, an experiment was planned whereby inoculation by this means might be simulated.

Method of Inoculation: The juice from a spindle

tuber was expressed upon a clean board by rubbing its freshly cut surface upon the board. A good type tuber was then cut in half with a sterile knife. The cut surface of one half was rubbed against the contaminated surface of the board. The other half was used as a check.

Each half was cut into two seed pieces with a sterile knife, the inoculated quarters being planted in one row and the uninoculated quarters just opposite in the adjoining row.

This experiment was repeated twelve times at the Speaker farm and fifteen times in the experimental field at Manhattan making fifty-four hills with inoculated material and fifty-four hills from uninoculated sister seed pieces.

7. Injury from Contaminated Planter Pickers: The pickers on a potato planter often injure the sprouts on seed pieces. This experiment was planned to determine whether pickers that are contaminated with the juice from spindle tubers might transmit the virus to healthy seed pieces when the sprouts are injured.

Method of Inoculation: A good type tuber showing short sprouts was selected for the experiment. This tuber was halved with a sterile knife. Inoculation was then attempted by piercing the sprouts on one half with a sharp needle that had just been inserted into a spindle

tuber.

The inoculated half was planted in one row and the uninoculated sister half was planted just opposite in an adjoining row to serve as a check.

This experiment was repeated six times at the Speaker farm at Kansas City and nine times in the experimental field at Manhattan, making a total of fifteen trials.

B. Spindle Tuber Expression Studies

The mode of expression of spindle tuber was studied by planting seed pieces from definite spindle tubers in a row beside apparently healthy good type tubers. Foliage symptoms were observed from time to time and the plants from spindle tubers were compared with those from good type tubers.

At harvest records were taken on the progeny of good type tubers and spindle tubers to determine tuber symptoms and yield.

C. Spindle Tuber Prevalence Studies

The prevalence of spindle tuber was studied by examining various lots of seed shipped into Kansas by Kaw Valley potato growers. The percentage of visible spindle tuber in each lot of seed was determined by making

counts of tubers in several sacks of seed. Counts were made in seventy-four lots of seed.

EXPERIMENTAL DATA

Utilizing the methods just described, studies were made of the transmission, expression and prevalence of spindle tuber. The results of these studies are herewith presented in tabular form. Each year's work is presented separately.

Investigations, 1926

A. Transmission Studies, 1926: The results of the transmission studies are shown in the following tables. These tables show the methods of inoculation, the number of plants used, the number of plants that produced spindle tuber progeny at harvest and the per cent of plants that produced spindle tuber progeny.

Table I. Results of Inoculating Healthy Seed Pieces with a Spindle Tuber by Various Methods. Harvested July 14, 1926.

Method of Inoculation	No. of Plants	No. of Plants S. T. Progeny	Per Cent of Plants S. T. Progeny
1. Insect transmission	4	1	25
1. Check plants in insect proof cage	4	0	0
2. (a) Contaminated needle punctures in leaves and petioles	50	6	12
2. (b) Maceration of leaves with contaminated fingers	30	0	0
3. Cutting knife; Inoculated halves	44	2	4.5
3. Uninoculated halves used as checks	44	0	0
4. Contact of cut surfaces. Inoculated halves	44	1	2.2
4. Uninoculated halves used as checks	44	0	0
5. Tuber Grafts	46	36	78.2
6. Planter box; Inoculated halves	54	0	0
6. Uninoculated halves used for checks	54	0	0
7. Sprout injuries; Inoculated halves	15	1	6.6
7. Uninoculated halves used for checks	15	0	0

Tubers from hills that did not show current season symptoms of spindle tuber from the various methods of inoculation were saved for planting in the greenhouse to determine whether or not they were carrying the spindle tuber virus but did not express either foliage or tuber symptoms in the first generation.

These good type tubers were planted in the greenhouse on October 25, 1926, and were harvested February 21, 1927.

This work is to be criticized from the standpoint that no healthy checks were planted in the greenhouse to determine what part of the infection was due to insect transmission in the field the previous season and what part was due to the artificial inoculations.

Table II. Results in Second Generation when Progeny of Spindle Tuber Inoculated Plants Were Grown in the Greenhouse, 1926.

Method Used to Inoculate Parent Plants	No. of Plants	No. of Plants S. T. Progeny	Per Cent of Plants S. T. Progeny
2. (a) Contaminated needle punctures in leaves and petioles	31	10	32.2
2. (b) Maceration of leaves with contaminated fingers	16	5	31.2
3. Cutting Knife	59	17	28.8
4. Contact of cut surfaces	59	3	5.0
7. Sprout Injuries	20	11	55.0

B. Expression Studies, 1926: Plants produced from spindle tubers were compared with plants from good type tubers of the same variety. The Irish Cobbler and the Early Ohio varieties were used. The foliage symptoms of spindle tuber were expressed as follows:

(1) Plants more or less dwarfed and erect growing.

(2) The angle between the petiole and stalk is very acute.

(3) Plants show rigidity and when bent over return quickly to an erect position.

(4) Leaves slightly dwarfed and usually show a ruffled margin.

(5) Foliage usually lighter green than in normal plants.

The tuber symptoms expressed were:

(1) Elongated or pointed at the bud end.

(2) Numerous, shallow or bulging eyes.

(3) Greatly decreased yield due to smaller tubers but not necessarily a smaller number of tubers.

(4) Early Ohio tubers lighter red in color than normal.

Yield records were taken to determine expression in yield by spindle tuber infected plants as compared with healthy plants from the same strain of seed.

Table III. Yields of Spindle Tubers Compared with Good Type Tubers. Irish Cobbler Variety. 1926.

Lot No.	Per Cent S. T. in seed	Average Yield Per Hill	
		Spindle Tuber lbs.	Good Type lbs.
1	0.9	.43	.54
2	3.5	.31	.60
3	3.9	.19	.32
4	8.5	.23	.62
5	3.4	.75	1.56
6	3.6	.32	.32
7	3.1	.28	.71
Average	3.6	.37	.72

C. Prevalence Studies, 1926: A survey was made of several lots of seed purchased by Kansas growers to determine the percentage of visible spindle tuber shipped into the state by northern seed growers.

The following table shows the lot numbers of the seed from which the counts were made, the kind of seed and the percentage of spindle tuber found in each lot.

Table IV. Per Cent of Spindle Tuber Contained in Various Lots of Seed Purchased by Kansas Potato Growers in 1926. Irish Cobbler Variety.

Lot No.	Kind of Seed	Per Cent Spindle Tuber
1	Certified	0.9
2	Commercial	3.5
3	Commercial	3.9
4	Commercial	8.5
5	Commercial	3.4
6	Commercial	3.6
7	Commercial	3.1
8	Commercial	2.3
9	Commercial	13.3
10	Commercial	4.4
11	Commercial	6.7
12	Commercial	5.9
13	Commercial	5.8
14	Commercial	1.7
15	Commercial	3.7
16	Commercial	3.0
17	Commercial	1.2
18	Commercial	3.4
19	Homegrown	0.0
20	Commercial	0.3
21	Commercial	2.9
22	Commercial	2.6

Table IV (Continued)

Lot No.	Kind of Seed	Per Cent Spindle Tuber
23	Commercial	0.2
24	Commercial	2.7
25	Commercial	3.2
26	Commercial	1.2
27	Commercial	2.0
28	Commercial	1.8
29	Commercial	1.1
30	Certified	0.3
31	Certified	0.3
32	Commercial	5.0
33	Commercial	0.8
34	Commercial	0.9
35	Commercial	1.3
36	Commercial	1.3
37	Commercial	0.4
38	Commercial	3.4
39	Commercial	1.7
40	Commercial	4.0
41	Commercial	2.8
42	Commercial	3.2
43	Commercial	3.4
44	Commercial	3.6
Average		2.9

Investigations, 1927

A. Transmission Studies, 1927: The results of the transmission studies are shown in the following tables. These tables show methods of inoculation, the number of plants used, the number of plants that produced spindle tuber progeny and the percentage of plants that produced spindle tuber progeny.

Table V. Results of Inoculating Healthy Seed Pieces with Spindle Tuber by Means of Cutting Knife and Seed Piece Contact. Harvested September 8, 1927.

Method of Inoculation	No. of Plants	No. of Plants S. T. Progeny	Per Cent of Plants S. T. Progeny	Per Cent due to Inoculation
Cutting Knife Inoculated halves	24	15	62.6	54.3
Uninoculated halves; Cutting Knife Check	24	2	8.3	
Contact of Cut Surfaces; Inoculated halves	36	21	58.3	52.8
Uninoculated halves; Contact Checks	36	2	5.5	

Second Generation Studies After Insect Transmission: Tubers were saved from the healthy tuber unit in the field that was surrounded by spindle tuber infected plants in 1926. Tubers from the healthy check that was planted in the insect proof cage and surrounded by spindle tubers were also saved. The object of this test was to determine

what per cent of the progeny of the plants surrounded by spindle tuber in 1926 would produce spindle tuber progeny in 1927.

Seed pieces from these tubers were planted separately in cages in 1927. The results obtained with the second generation are shown in the following table:

Table VI. Results in Second Generation when Progeny of Caged and Uncaged Plants Produced in 1926 were Grown in Cages in 1927.

Method Used to Inoculate Parent Plants	No. of Plants	No. of Plants S. T. Progeny	Per Cent of Plants S. T. Progeny
I. Insect Transmission from nearby plants	7	3	43
I. Check plants in insect proof cage	9	0	0

B. Expression Studies, 1927: In 1927 the foliage symptoms of spindle tuber infected plants were similar to those described in the 1926 expression studies. The tuber symptoms were also similar; however, additional yield expression data were obtained. The results are shown in the following table.

Table VII. Yields of Spindle Tubers Compared with Good Type Tubers. Irish Cobbler Variety. 1927.

Lot No.	Per Cent S. T. in seed	Average Yield Per Hill	
		Spindle Tuber	Good Type
1	2.2	1.0	1.33
2	3.4	.31	1.61
3	3.6	.48	1.36
4	3.6	.41	1.36
5	2.8	.68	1.24
Average	3.1	.57	1.2

C. Prevalence Studies, 1927: Further studies on prevalence were made in 1927 to determine the percentage of visible spindle tuber shipped into Kansas.

The following table shows the various lots of seed and the per cent of spindle tuber contained therein:

Table VIII. Per Cent of Spindle Tuber Contained in Various Lots of Seed Purchased by Kansas Potato Growers in 1927. Irish Cobbler Variety.

Lot No.	Kind of Seed	Per Cent Spindle Tuber
1	Certified	1.7
2	Certified	0.7
3	Certified	1.0
4	Certified	2.5
5	Certified	2.1
6	Certified	3.0

Table VIII (Continued)

Lot No.	Kind of Seed	Per Cent Spindle Tuber
7	Certified	0.6
8	Certified	1.3
9	Commercial	6.1
10	Commercial	3.3
11	Commercial	3.2
12	Commercial	4.8
13	Commercial	6.3
14	*Field Inspection O.K.	5.1
15	*Field Inspection O.K.	9.6
16	*Field Inspection O.K.	5.0
17	*Field Inspection O.K.	5.9
18	*Field Inspection O.K.	2.0
19	*Field Inspection O.K.	7.1
20	*Field Inspection O.K.	7.6
21	*Field Inspection O.K.	6.9
22	Commercial	1.3
23	Commercial	1.7
24	Commercial	1.7
25	Commercial	11.1
26	Commercial	5.6
27	Commercial	9.0
28	Commercial	11.0

Table VIII (Continued)

Lot No.	Kind of Seed	Per Cent Spindle Tuber
29	Commercial	5.4
30	Commercial	7.6
Average		4.6

*The field inspections were passed for seed certification but the final bin inspection necessary for certification was not made.

DISCUSSION

Transmission of spindle tuber was secured by several methods of inoculation. Current season symptoms were obtained by inoculation of the parent tubers and by introduction of the juice from spindle tuber infected plants into growing healthy plants by various means.

Insects feeding on spindle tuber infected plants in the field transferred the virus to healthy plants which became infected. However, not all of the progeny of the infected plants showed current season symptoms. This was shown by the fact that three out of seven apparently good type tubers, produced in 1926 on plants in the field that were surrounded by spindle tubers, yielded spindle tuber progeny in 1927. The progeny of healthy checks grown in the cage in 1926 and surrounded by infected plants produced only good type tubers in 1927.

Needle punctures simulating insect punctures yielded

twelve per cent spindle tuber in 1926. These plants were not grown under cages and no checks were used; therefore, it is impossible to tell exactly how much of the spindle tuber obtained was from ordinary field insect transmission. The evidence points to very little insect transmission in the plot where the transmission studies were conducted. This is probable because the plot was planted with seed pieces from only good type tubers and is further substantiated by the fact that not one of the checks used in connection with other inoculations showed current season symptoms.

All inoculations by leaf maceration were unsuccessful as far as the securing of current season symptoms was concerned. Thirty plants were inoculated, but not one showed any sign of spindle tuber during the growing season or when the plants were harvested.

Cutting knife inoculations were made with forty-four seed pieces in 1926. Only two plants or 4.5 per centshowed current season symptoms of spindle tuber. These plants were harvested on July 14. None of the checks were infected. In 1927 the plants were allowed to stand in the field until September 2, or about six weeks longer than in 1926. There were twenty-four plants in the experiment. Fifteen, or 62.5 per cent, showed current season symptoms

of spindle tuber. Two plants in the check row also showed spindle tuber, indicating that the disease was present in one tuber before it was cut for seed. Omitting these two plants there was still 54.3 per cent spindle tuber in the inoculated row.

Leaving the plants in the field for a longer period apparently allowed time for the disease to express itself during the current season.

In the greenhouse the second generation from cutting knife inoculated seed in 1926 showed 28.8 per cent spindle tuber infection. As previously noted only 4.8 per cent of the plants showed current season symptoms in the first generation. In the greenhouse no checks were included from uninoculated seed, hence no allowance is made for insect transmission in the field during the previous season.

Contact of freshly cut surfaces of spindle tubers and healthy tubers gave evidence of some transmission in 1926 when forty-four trials were made and one plant showed current season symptoms. The checks showed no symptoms. In 1927 plants from the contact inoculated tubers were allowed to stand until September 2. Of these inoculation trials 32.8 per cent were successful.

Cut surface inoculation and cutting knife inoculation probably take place very frequently under field conditions. The symptoms, however, apparently do not become evident

for a considerable period following infection. The Kansas crop is usually dug in July and the first half of August which no doubt accounts for lack of expression of current season symptoms in the field.

Tuber grafting was the most efficient means of transmitting the disease for securing current season symptoms. Forty-six inoculations were made, of which thirty-six, or 78.2 per cent, were successful. The contact of the cut surface of the spindle tuber graft and the healthy tuber is maintained for a considerable time and this is probably the reason why a high percentage of infection was secured. See Plates II and III.

Planter box inoculations were unsuccessful in all of the fifty-four trials made. The reason for this has not been determined.

Sprout injuries inflicted with a needle that had previously been contaminated by pricking a spindle tuber gave one successful inoculation in fifteen trials. In the greenhouse the second generation produced 55 per cent spindle tuber progeny. No checks were used, hence it is not known how much insect transmission might have occured in the field.

The spindle tuber expression studies indicate that foliage symptoms are expressed by more or less dwarfed and erect growth, the angle between the petiole and the stalk

being very acute. Infected plants show rigidity; the leaves show dwarfing and ruffling at the margins. See Plates IV and V.

The tuber symptoms are expressed by elongation, numerous shallow and bulging eyes and greatly decreased yield. Yield records indicate that the weight of spindle tuber hills is about one-third to one-half that of hills from good type tubers.

The prevalence of visible spindle tuber in seed shipped into the state by Kansas growers causes a greater loss than was heretofore imagined. The growers have begun to realize this in the last few years and are carefully sorting over their seed and throwing out the visible spindle tuber. Some are using certified seed.

A comparison of the percentages of spindle tuber in certified and commercial seed indicate that the certified seed contains far less spindle tuber than commercial seed. This is due to the continuous roguing out of spindle tuber infected plants in the field by certified seed growers.

SUMMARY

1. All types of potato mosaic studied express themselves in decreased yields even though the infected plants show no mottling or other foliage symptoms under field conditions.

2. The mosaic symptoms expressed on potato plants often change as the season progresses. A plant showing rugose mosaic early in the season may show only mild mosaic symptoms or the symptoms may be entirely masked by the time the plants are in bloom.

3. Mild mosaic symptoms are usually masked by the time the plants are in bloom.

4. Evidence was obtained showing that spindle tuber can be transmitted (a) by insects, (b) by contaminated cutting knives, (c) by contact of diseased and healthy seed pieces, (d) by tuber grafts, (e) by injuries inflicted to sprouts by contaminated tools.

5. Spindle tuber expresses itself in top growth as follows: (a) Plants are dwarfed and very erect. (b) The angle between the petiole and the stalk is very acute. (c) Plant is rigid and when bent over returns quickly to an erect position. (d) Leaves are dwarfed and usually have slightly ruffled margin. (e) The color of the infected plants is usually a lighter green than normal.

6. The yield from spindle tuber infected plants is about 60 per cent by weight as much as the yield from good type tubers.

7. Counts made in various lots of certified and commercial potato seed show that certified seed contains far less spindle tuber than does commercial seed.

BIBLIOGRAPHY

Barrus, M. F. and Chupp, Chas.
1926. Potato Diseases and their Control. Cornell Ext. Bul. 135:38-125.

Beijerinck
1899. Uber ein Contagium Vivium Fluidum als Ursache der Fleckenkrankheit der Tabaksblatter Centralblatt fur Bact. etc. 5:27 (Part 2).

Elmer, O. H.
1922. Mosaic Cross-Inoculation and Insect Transmission Studies. Science N. S. 41:370-372.

Elmer, O. H.
1925. Transmissibility and Pathological Effects of the Mosaic Disease. Iowa State Agr. Exp. Sta. Res. Bul. 82.

Fernow, K. H.
1925. Interspecific Transmission of Mosaic Diseases in Plants. Cornell Agr. Exp. Sta. Memoir 96.

Folsom, D.
1923. Potato Spindle Tuber. Me. Agr. Exp. Sta. Bul. 312.

Folsom, D.
1921. Potato Leafroll. Me. Agr. Exp. Sta. Bul. 297.

Goss, R. W.
1926. Transmission of Potato Spindle Tuber by Cutting Knives and Seed Piece Contact. Phytopathology 16:299-304.

Goss, R. W. and Peltier, G. L.
1925. Further Studies on the Effect of Environment on Potato Degeneration Diseases. Nebr. Agr. Exp. Sta. Res. Bul. 29.

Goss, R. W.
1924. Effect of Environment on Potato Degeneration Diseases. Nebr. Agr. Exp. Sta. Res. Bul. 26.

Goss, R. W.
1925. Two Important Groups of Nebraska Potato Diseases. Nebr. Ext. Circ. 1256.

*Iwanowski, D.
1892. Uber die Mosaikkrankheit der Tabakspflanze. Bull. acad. Imp. Sci. St. Petersb. N. A. 3:67-70.

Jehle, R. A.
1926. Disastrous Effect of Mosaic on the McCormick Potato. Md. Agr. Exp. Sta. Bul. 282.

Johnson, James.
1926. Some Points of View on the Plant Virus Problem. Phytopathology 16:745-751.

Johnson, James.
1927. The Classification of Plant Viruses. Wis. Agr. Exp. Sta. Res. Bul. 76.

Krantz, F. A. and Bisby, G. R.
1921. Relation of Mosaic to Running Out of Potatoes in Minnesota. Minn. Agr. Exp. Sta. Bul. 197.

*Martin, W. H.
1922. "Spindle Tuber," a New Potato Trouble, Hints to Potato Growers. N. J. State Potato Assn., Vol. 8, Dec., 1922.

*Mayer, Adolf.
1886. Uber die Mosaikkrankheit des Tabaks. Die Landwirtschaftliche Versuchs-Stationen. 32:450-467.

Nelson, Ray.
1922. The Occurrence of Protozoa in Plants Affected with Mosaic and Related Diseases. Mich. Agr. Exp. Sta. Tech. Bul. 58.

Schultz, E. S.
1924. Why Potatoes Run Out. U. S. D. A. Farmers Bul. 1436.

Schultz, E. S., Folsom, D. and Bonde, R.
1926. Potato Degeneration Diseases: Natural Spread and Effect upon Yield. Me. Agr. Exp. Sta. Bul. 331.

Schultz, E. S. and Folsom, D.
1925. Infection and Dissemination Experiments with Degeneration Diseases of Potatoes. Observations in 1923. Journ. Agr. Res. 30:493-528.

Schultz, E. S. and Folsom, D.
1923. Transmission, Variation and Control of Certain Degeneration Diseases of Irish Potatoes. Journ. Agr. Res. 25:43-115.

Stewart, F.C.
1924. Control of Leafroll and Mosaic in Potatoes by Isolating and Roguing the Seed Plat. N. Y. Agr. Exp. Sta. Bul. 522.

Tompkins, C. M.
1926. Influence of the Environment on Potato Mosaic Symptoms. Phytopathology 16:581-607.

Werner, H. O.
1925. The Spindle Tuber Disease as a Factor in Seed Potato Production. Nebr. Agr. Exp. Sta. Res. Bul. 32.

Woods, A. F.
1902. Observations of the Mosaic Disease of Tobacco. U. S. D. A., B.P. I. Bul. 18:1-24.

Quoted but not read.

Good type tubers used in the Spindle Tuber Transmission Studies. Such tubers as these were inoculated by the various methods described.

Spindle tuber transmission by tuber grafts. A plug was cut from a spindle tuber and fitted into the hole in a good type tuber.

A tuber graft and its progeny. The old seed piece did not decay and the graft from the spindle tuber still shows.

A spindle tuber infected plant. Note the erect habit of growth, the sharp angle between the petiole and the main stem and the ruffling of the leaf margins.

A healthy potato plant. Note bushy habit of growth in contrast to spindle tuber infected plant in Plate IV.